Fermilab

ESTIMATED τ NEUTRINO FLUXES FROM A BEAM DUMP AT 400 GEV AND 1000 GEV

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An interesting test to observe the τ neutrino associated with the τ lepton using neutrino detectors has been proposed[1]. It will be one of the most exciting experiments which can be performed at Fermilab when the Tevatron becomes operational in the proton energy region of 1000 GeV[2].

Fluxes of τ neutrinos and antineutrinos from a beam dump for the incident proton energy of 400 GeV and 1000 GeV were calculated using a Monte Carlo program. The following assumptions were made in the calculations:

1. τ neutrinos, ν_τ, were produced from the F^+ meson decay, $F^+ \to \tau^+ \nu_\tau$ (B.R. = 3%), and the τ^- decay, $\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau$ (B.R. = 38%), $\pi^- \nu_\tau$ (B.R. = 10%) and $\rho^- \nu_\tau$ (B.R. = 20%), where the ℓ is the e or μ. The τ^- is the decay product of the F^-. Conversely, τ antineutrinos, $\bar{\nu}_\tau$, were produced from the F^- and τ^+ decays. The mass of the F was 2.06 GeV.
2. Other decay modes of the τ were not included.
3. The helicity state of the τ from the F decay was not taken into account in the τ decay.
4. The energy spectrum of the ν_τ from $\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau$ had the form of $(3-2\varepsilon)\,\varepsilon^3$, where ε is the ratio of the energy of the ν_τ to its maximum possible energy of 0.89 GeV (half the τ mass)[4].
5. The production cross section of the $F^+ F^-$ pair from proton-nucleus interactions had the form[5,6]

$$E \frac{d^3\sigma}{dp^3} \propto \frac{g(p_t,s)\, G(x)}{\left(\sqrt{p_t^2 + M_F^2} + 2.7\right)^{16.5}}$$

where

$$g(p_t,s) = \begin{cases} \exp(-1.06 p_T), & \text{for } p_T < 1.0 \\ \exp\{(1-p_T)/\sqrt{s} - 1.06\}, & \text{for } p_T > 1.0 \end{cases}$$

$$G(x) = 1, \text{ for } |x| < 0.25$$
$$\left\{\frac{1-|x|}{0.75}\right\}^4, \text{ for } |x| > 0.25.$$

6. The integrated cross section of the F pair production per nucleon from 0 to 200 mrad in the laboratory system was 10 μb.
7. The cross section of the F pair production had the same A dependence as the proton absorption cross section; i.e. roughly proportional to $A^{2/3}$.
8. The lifetime of the F was so short that they decayed before being absorbed by beam dump material.
9. The beam dump was made of copper.
10. The distance between the beam dump and the detector was 250 m as proposed previously[7].

Figures 1, 2, and 3 plot calculated τ neutrino fluxes for three angular ranges which are defined with respect to the incident proton beam direction at the beam dump. The angular ranges are 0 to 2 mrad, 4 to 6 mrad, and 8 to 10 mrad. The proton energy is 1000 GeV. Contributions from all the decay processes are shown separately. The ν_τ spectrum from the $F^+ \to \tau^+\nu_\tau$ is peaked at a relatively low energy due to a small mass difference between the F^+ and τ^+. Decay processes of the τ which are not considered here should yield τ neutrinos with much lower energies than those from the $\nu_\tau \ell^- \bar{\nu}_\ell$, $\nu_\tau \pi^-$ and $\nu_\tau \rho^-$ decays. Fluxes of τ antineutrinos are exactly the same as those of τ neutrinos for the production processes considered here. Figure 4 shows summed ν_τ fluxes for the three angular ranges.

Table I gives computed event rates of τ neutrino interactions at 1000 GeV for the three angular ranges. We assumed that the total cross section of ν_τ nucleon interactions was 0.61 $E_{\nu\tau}$ (in GeV) x 10^{-38} cm^2. A neutrino detector with a fiducial volume of 100 tons was used.

Electron and muon neutrinos (and antineutrinos) produced in the beam dump constitute the major source of backgrounds for experiments to study ν_τ (or $\bar{\nu}_\tau$) interactions. Computed electron (or muon) neutrino (or antineutrino) fluxes from the $D(1.86) \to Ke^+\nu_e$ (or $Ke^-\bar{\nu}_e$, or $K\mu^+\nu_\mu$ or $K\mu^-\bar{\nu}_\mu$) in the beam dump as a function of the angle are shown in Figure 5. We assumed that the production cross section for the D(1.86) had the

Table I. Event rates of τ neutrino interactions for a detector with a fiducial volume of 100 tons. The incident proton energy was 1000 GeV. The cross section for the F pair production was assumed to be 10 μb. The distance between the beam dump and the detector was 250 m.

Angular Range (mrad)	Event Rates/10^{18} Protons
0 - 2	810
4 - 6	350
8 - 10	120

same form as for the F pair production (see assumption 4) and that $\sigma\cdot BR \simeq 10\ \mu b$. Neutrino energy distributions from the D decay were taken from Reference 5. The beam dump arrangement was the same as in the τ neutrino case. Note that the four kinds of ordinary neutrinos from the D decay have essentially identical flux distributions.

Muon neutrino and antineutrino fluxes for $\pi^{\pm}$ and $K^{\pm}$ decays in the beam dump at 1000 GeV are shown in Figure 6. The beam dump arrangement was the same as in the τ neutrino case. Stefanski-White's parametrization[8] was used for charged pion and kaon production cross sections. Figure 7 shows the angular dependence of muon neutrino fluxes for π^{+} and K^{+}. Angular ranges are 0 to 2 mrad, 4 to 6 mrad, and 8 to 10 mrad. They decrease much more rapidly as the angle increases compared to the τ neutrino fluxes from the τ decay (see Figure 4).

Electron neutrino and antineutrino fluxes from the K_L^{o} and K_{e3} decays in the beam dump are substantially small compared to muon neutrino and antineutrino fluxes from the π and K decay in the beam dump as discussed previously for the incident proton energy of 400 GeV[9].

Figure 8 plots the computed ν_τ flux, neutrino flux from the D(1.86) decay and ν_μ flux from the π^+ and K^+ decays in the copper beam dump at 1000 GeV. The angular range was 0 to 2 mrad. Also shown is the ν_μ flux for the double horn system at 400 GeV for comparison. If the cross sections for D and F productions are proportional to A instead of $A^{2/3}$ dependence, then the τ neutrino flux and neutrino fluxes for the D decay increase by a factor of 4 for the copper beam dump.

Computed τ neutrino fluxes for the incident proton energy of 400 GeV are shown in Figures 9 and 10. Various fluxes produced in a beam dump (aluminum) for the incident proton energy of 400 GeV were discussed extensively in Reference 9.

Valuable discussions with Dr. C.H.Albright and Dr. T.Yamanouchi are greatly acknowledged.

References

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3. G. J. Feldman, Neutrino - 78, P. 647, Purdue University, April, 1978.
   W. Bacino et al., Phys. Rev Letters, 42, 6(1979).

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7. D. Cline, S. Mori and R. Stefanski, TM-802, July 1978.

8. R. Stefanski and H. White, Jr., FN-292, 1976.

9. S. Mori, TM-774, March 1978.

Figure Captions

Figure 1. Computed ν_τ fluxes for a beam dump at 1000 GeV. The cross section for the F pair production was assumed to be 10 μb. The angular range was 0 to 2 mrad. The distance between the beam dump and the detector was 250 m.

Figure 2. Computed ν_τ fluxes for a beam dump at 1000 GeV. The cross section for the F pair production was assumed to be 10 μb. The angular range was 4 to 6 mrad. The distance between the beam dump and the detector was 250 m.

Figure 3. Computed ν_τ fluxes for a beam dump at 1000 GeV. The cross section for the F pair production was assumed to be 10 μb. The angular range was 8 to 10 mrad. The distance between the beam dump and the detector was 250 m.

Figure 4. Angular dependence of computed ν_τ fluxes for a beam dump at 1000 GeV. The cross section for the F pair production was assumed to be 10 μb. The angular ranges were 0 to 2, 4 to 6 and 8 to 10 mrad. The distance between the beam dump and the detector was 250 m.

Figure 5. Computer electron (or muon) neutrino (or antineutrino) fluxes from the $D(1.86) \to Ke^+\nu_e$ decay for a beam dump as a function of the angle. The incident proton energy was 1000 GeV. We assumed that $\sigma(D\bar{D})\cdot BR = 10$ μb. The angular ranges were 0 to 2, 4 to 6, and 8 to 10 mrad. The distance between the beam dump and the detector was 250 m.

Figure 6. Computed muon neutrino and antineutrino fluxes from the π and K decays in a beam dump at 1000 GeV. The beam dump was made of copper. The distance between the beam dump and the detector was 250 m.

Figure Captions (cont.)

Figure 7. Angular depencence of computed muon neutrino fluxes from the π and K decays in a beam dump at 1000 GeV. The beam dump was made of copper. The angular ranges were 0 to 2, 4 to 6, and 8 to 10 mrad. The distance between the beam dump and the detector was 250 m.

Figure 8. Computed ν_τ flux, neutrino flux from the D(1.86) decay and ν_μ flux from the π and K decays from a beam dump at 1000 GeV. The beam dump was made of copper. The angular range was 0 to 2 mrad. The distance between the beam dump and the detector was 250 m. Also shown is the ν_μ flux for the double horn system for the incident proton energy of 400 GeV.

Figure 9. Computed ν_τ fluxes for a beam dump at 400 GeV. The cross section for the F pair production was assumed to be 10 μb. The angular range was 0 to 2 mrad. The distance between the beam dump and the detector was 250 m.

Figure 10. Angular dependence of computed ν_τ fluxes for a beam dump at 400 GeV. The cross section for the F pair production was assumed to be 10 μb. The angular ranges were 0 to 2, 4 to 6, and 8 to 10 mrad. The distance between the beam dump and the detector was 250 m.

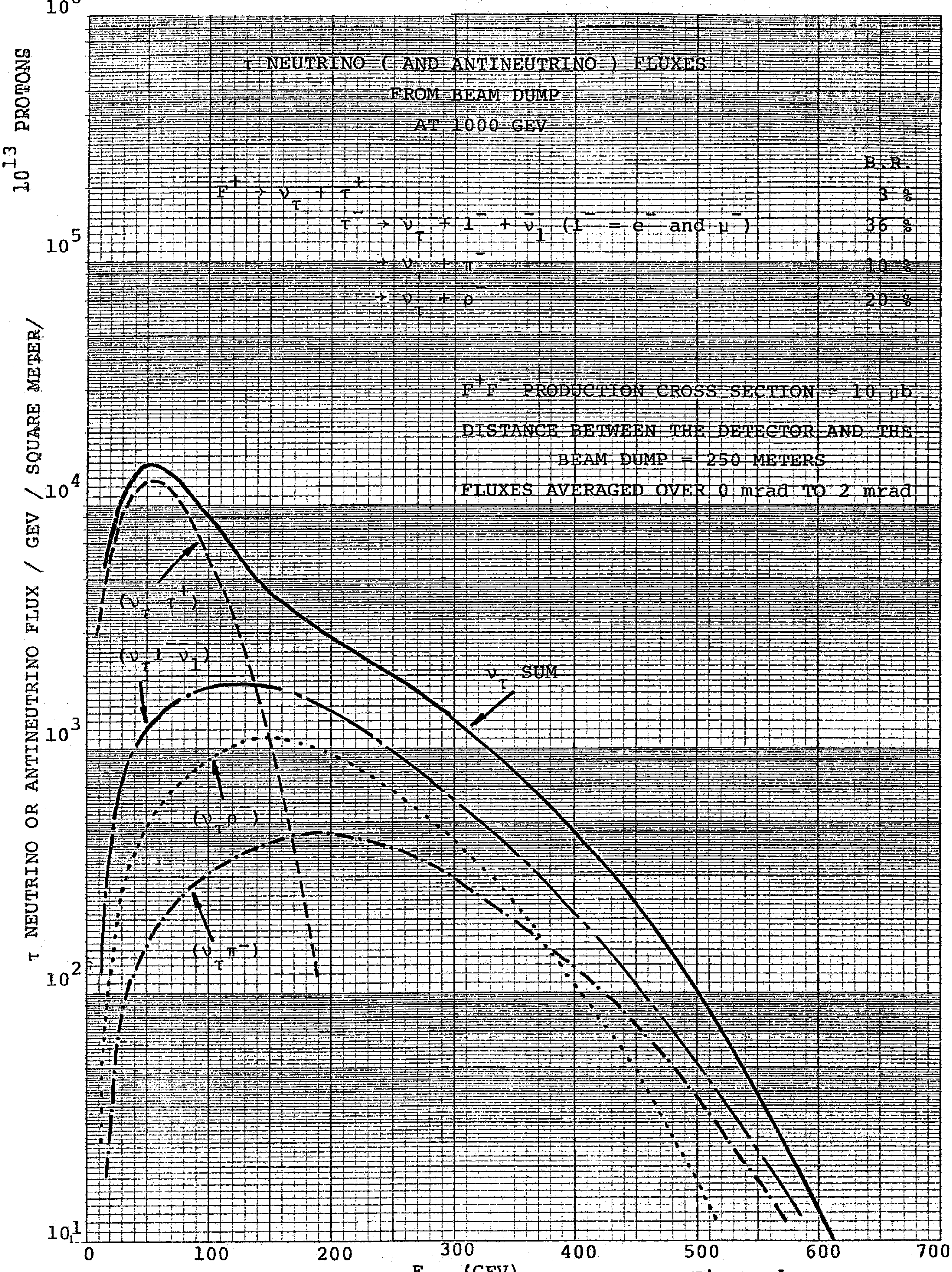

τ NEUTRINO (AND ANTINEUTRINO) FLUXES
FROM BEAM DUMP
AT 1000 GEV
B.R.
F+ → ντ + τ+ 3 %
τ- → ντ + l- + ν̄l (l- = e- and μ-) 36 %
→ ντ + π- 10 %
→ ντ + ρ- 20 %
F+F- PRODUCTION CROSS SECTION = 10 μb
DISTANCE BETWEEN THE DETECTOR AND THE
BEAM DUMP = 250 METERS
FLUXES AVERAGED OVER 0 mrad TO 2 mrad
(ντ τ+)
(ντ l- ν̄l)
(ντ ρ-)
(ντ π-)
ντ SUM
τ NEUTRINO OR ANTINEUTRINO FLUX / GEV / SQUARE METER/ 10^13 PROTONS
10^1
10^2
10^3
10^4
10^5
10^6
0
100
200
300
400
500
600
700
Eντ (GEV)

Figure 1.

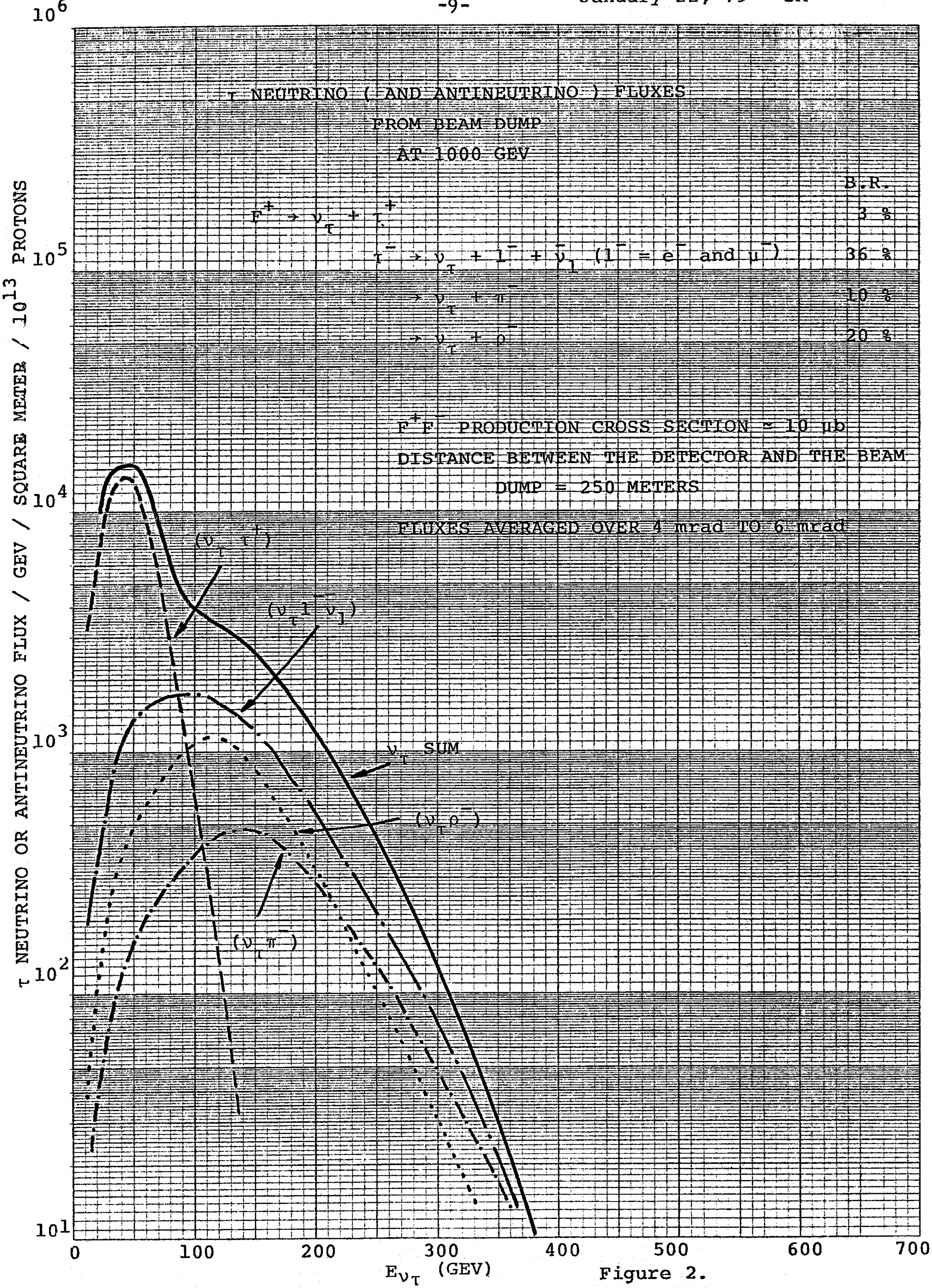

τ NEUTRINO (AND ANTINEUTRINO) FLUXES
FROM BEAM DUMP
AT 1000 GEV
B.R.
$F^+ \to \nu_\tau + \tau^+$ 3 %
$\tau^- \to \nu_\tau + l^- + \bar{\nu}_l$ (l^- = e^- and μ^-) 36 %
$\to \nu_\tau + \pi^-$ 10 %
$\to \nu_\tau + \rho^-$ 20 %
F^+F^- PRODUCTION CROSS SECTION ≈ 10 μb
DISTANCE BETWEEN THE DETECTOR AND THE BEAM DUMP = 250 METERS
FLUXES AVERAGED OVER 4 mrad TO 6 mrad
$(\nu_\tau\ \tau^+)$
$(\nu_\tau l^- \bar{\nu}_l)$
ν_τ SUM
$(\nu_\tau \rho^-)$
$(\nu_\tau \pi^-)$
τ NEUTRINO OR ANTINEUTRINO FLUX / GEV / SQUARE METER / 10^{13} PROTONS
E_{ν_τ} (GEV)
10^6
10^5
10^4
10^3
10^2
10^1
0
100
200
300
400
500
600
700

Figure 2.

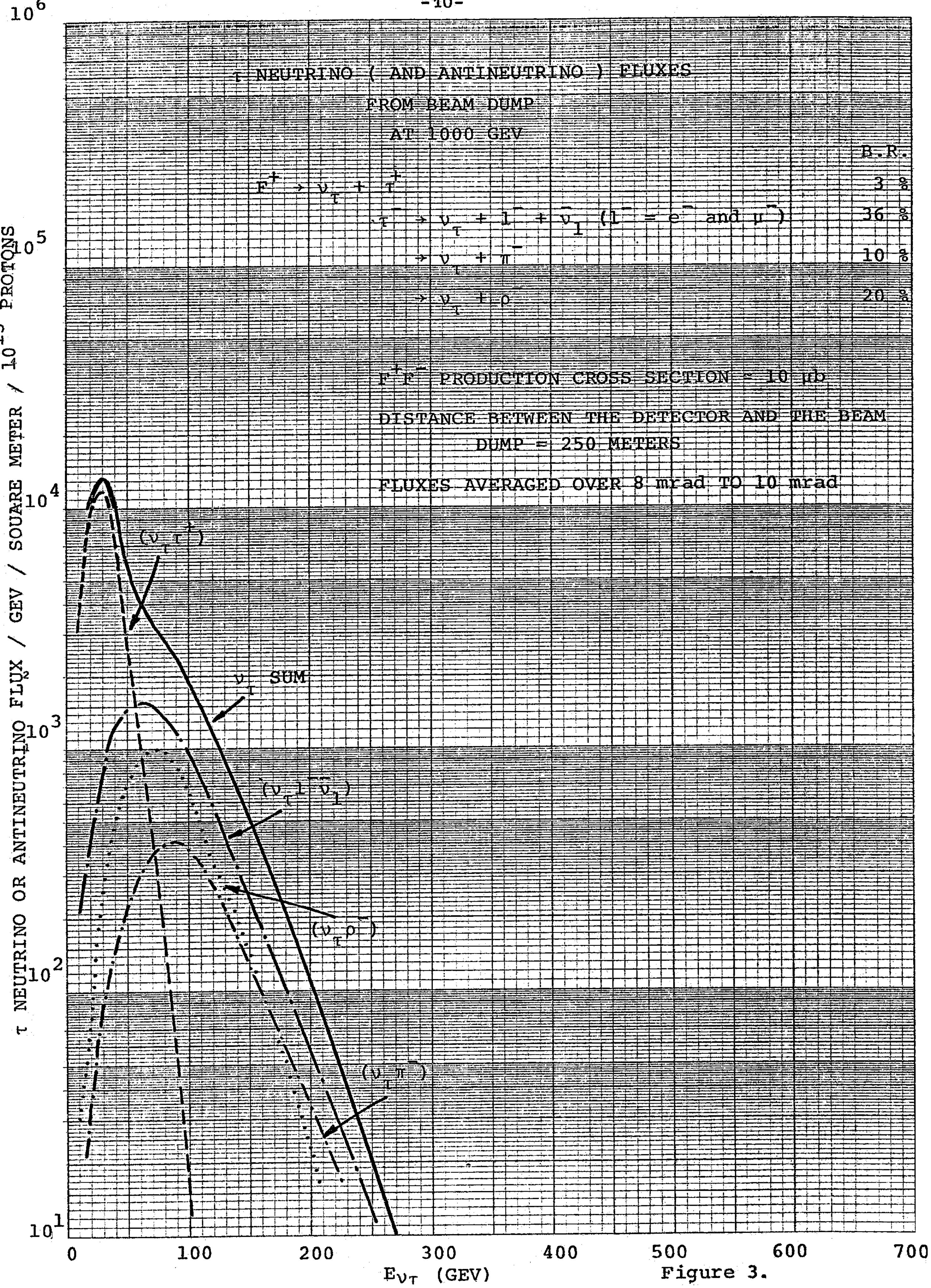

τ NEUTRINO (AND ANTINEUTRINO) FLUXES
FROM BEAM DUMP
AT 1000 GEV
B.R.
$F^+ \to \nu_\tau + \tau^+$ 3 %
$\tau^- \to \nu_\tau + l^- + \bar{\nu}_l$ (l^- = e^- and μ^-) 36 %
$\to \nu_\tau + \pi^-$ 10 %
$\to \nu_\tau + \rho$ 20 %
F^+F^- PRODUCTION CROSS SECTION ~ 10 μb
DISTANCE BETWEEN THE DETECTOR AND THE BEAM DUMP = 250 METERS
FLUXES AVERAGED OVER 8 mrad TO 10 mrad
$(\nu_\tau \tau^+)$
ν_τ SUM
$(\nu_\tau l^- \bar{\nu}_l)$
$(\nu_\tau \rho^-)$
$(\nu_\tau \pi^-)$
τ NEUTRINO OR ANTINEUTRINO FLUX / GEV / SQUARE METER / 10^{13} PROTONS
10^6
10^5
10^4
10^3
10^2
10^1
0
100
200
300
400
500
600
700
E_{ν_τ} (GEV)

Figure 3.

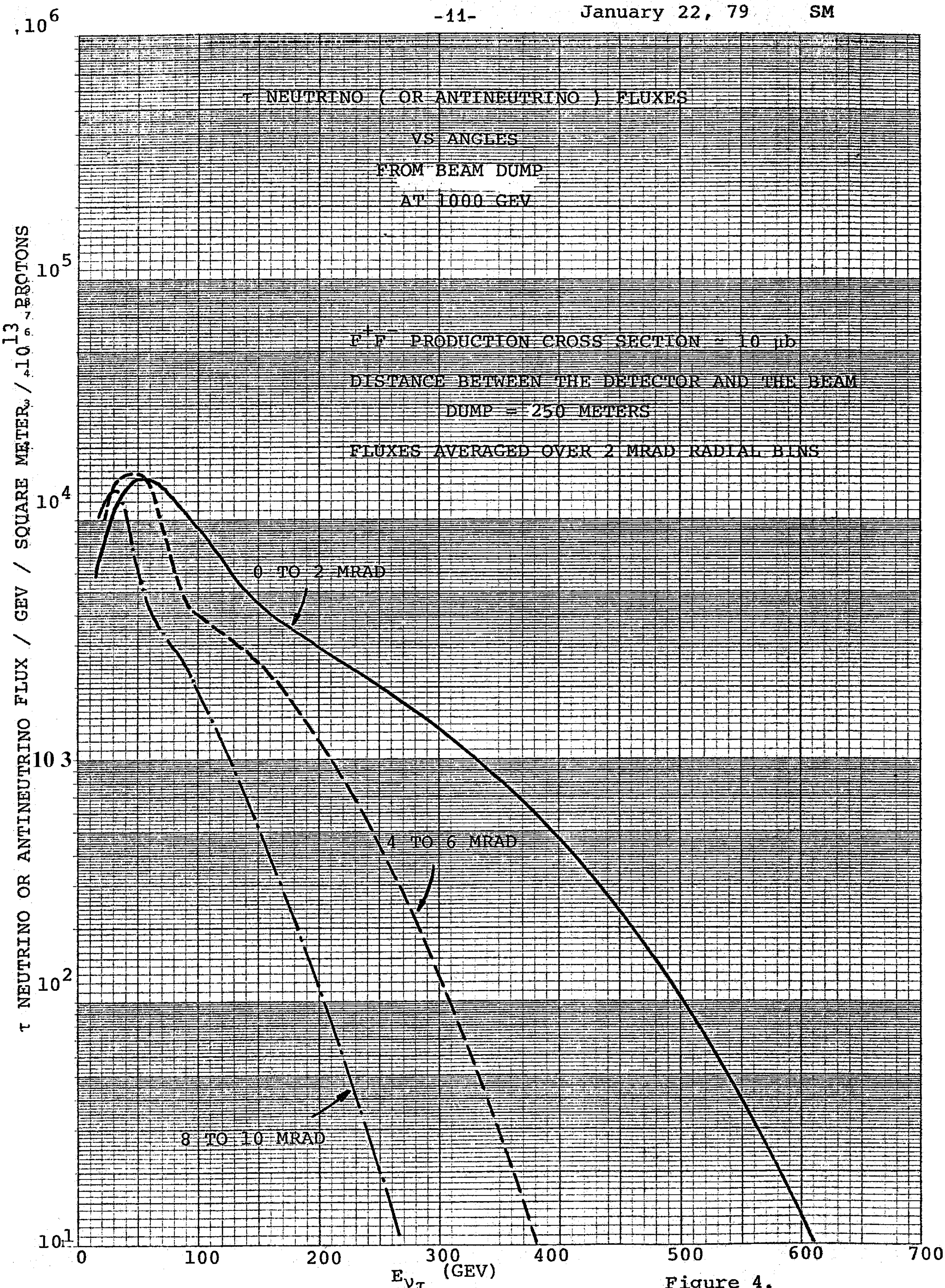
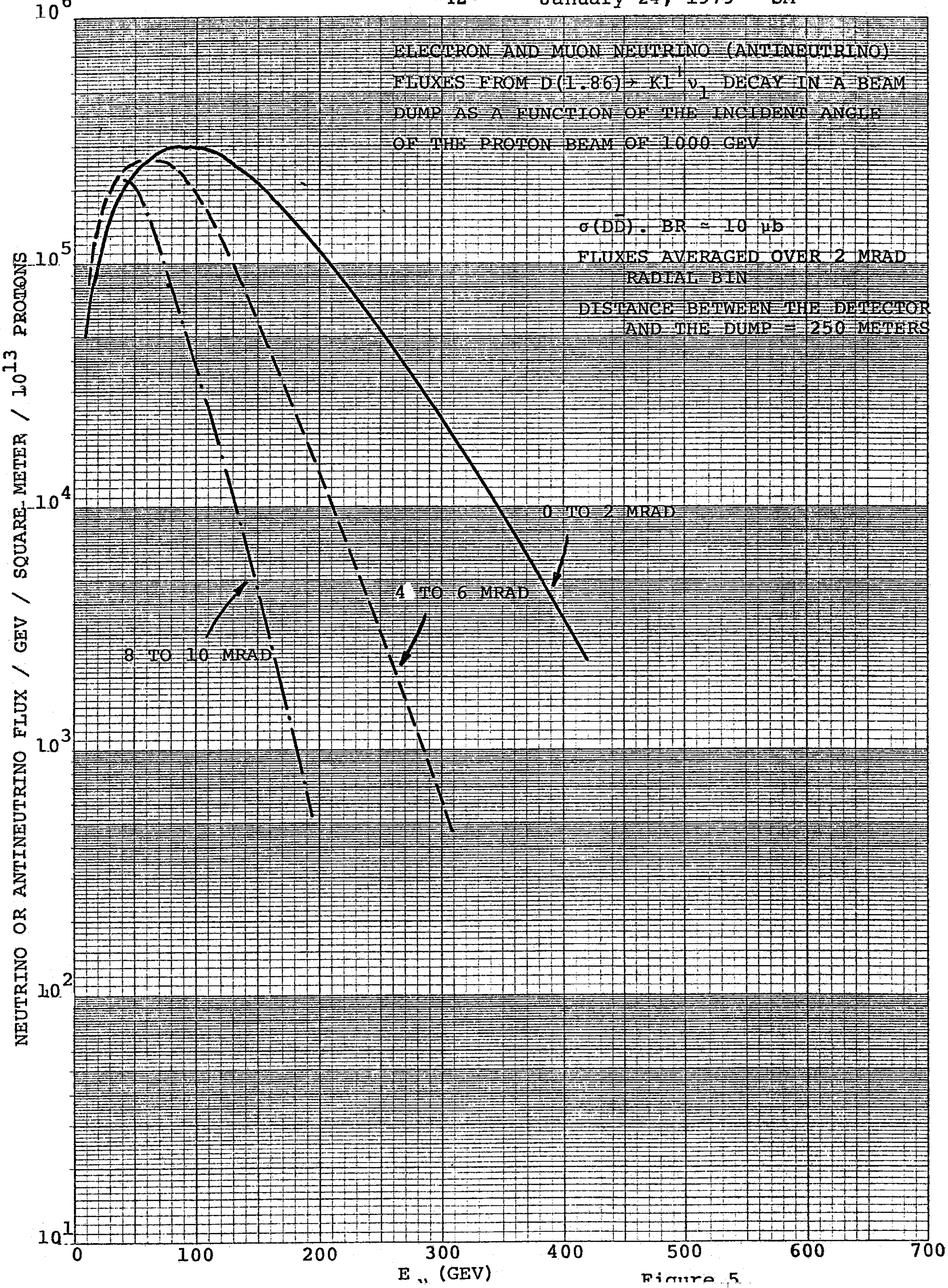

τ NEUTRINO (OR ANTINEUTRINO) FLUXES
VS ANGLES
FROM BEAM DUMP
AT 1000 GEV
F^+F^- PRODUCTION CROSS SECTION ~ 10 μb
DISTANCE BETWEEN THE DETECTOR AND THE BEAM DUMP = 250 METERS
FLUXES AVERAGED OVER 2 MRAD RADIAL BINS
0 TO 2 MRAD
4 TO 6 MRAD
8 TO 10 MRAD
τ NEUTRINO OR ANTINEUTRINO FLUX / GEV / SQUARE METER / 10^{13} PROTONS
10^6
10^5
10^4
10^3
10^2
10^1
0
100
200
300
400
500
600
700
E_{ν_τ} (GEV)

Figure 4.



ELECTRON AND MUON NEUTRINO (ANTINEUTRINO) FLUXES FROM D(1.86) → Kl⁺ν_l DECAY IN A BEAM DUMP AS A FUNCTION OF THE INCIDENT ANGLE OF THE PROTON BEAM OF 1000 GEV
σ(DD̄). BR ≈ 10 μb
FLUXES AVERAGED OVER 2 MRAD RADIAL BIN
DISTANCE BETWEEN THE DETECTOR AND THE DUMP = 250 METERS
0 TO 2 MRAD
4 TO 6 MRAD
8 TO 10 MRAD
NEUTRINO OR ANTINEUTRINO FLUX / GEV / SQUARE METER / 10^13 PROTONS
E_ν (GEV)

Figure 5

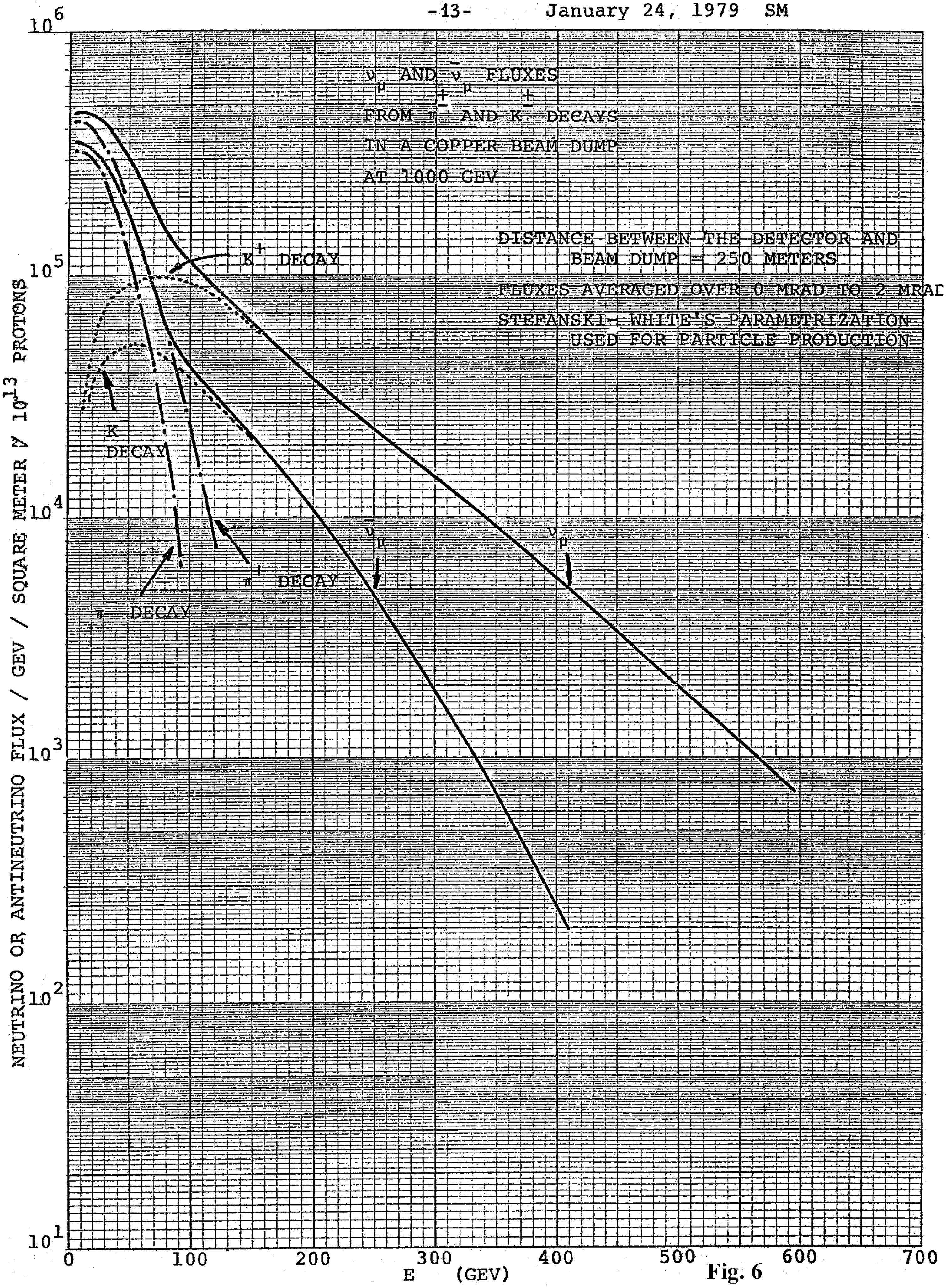
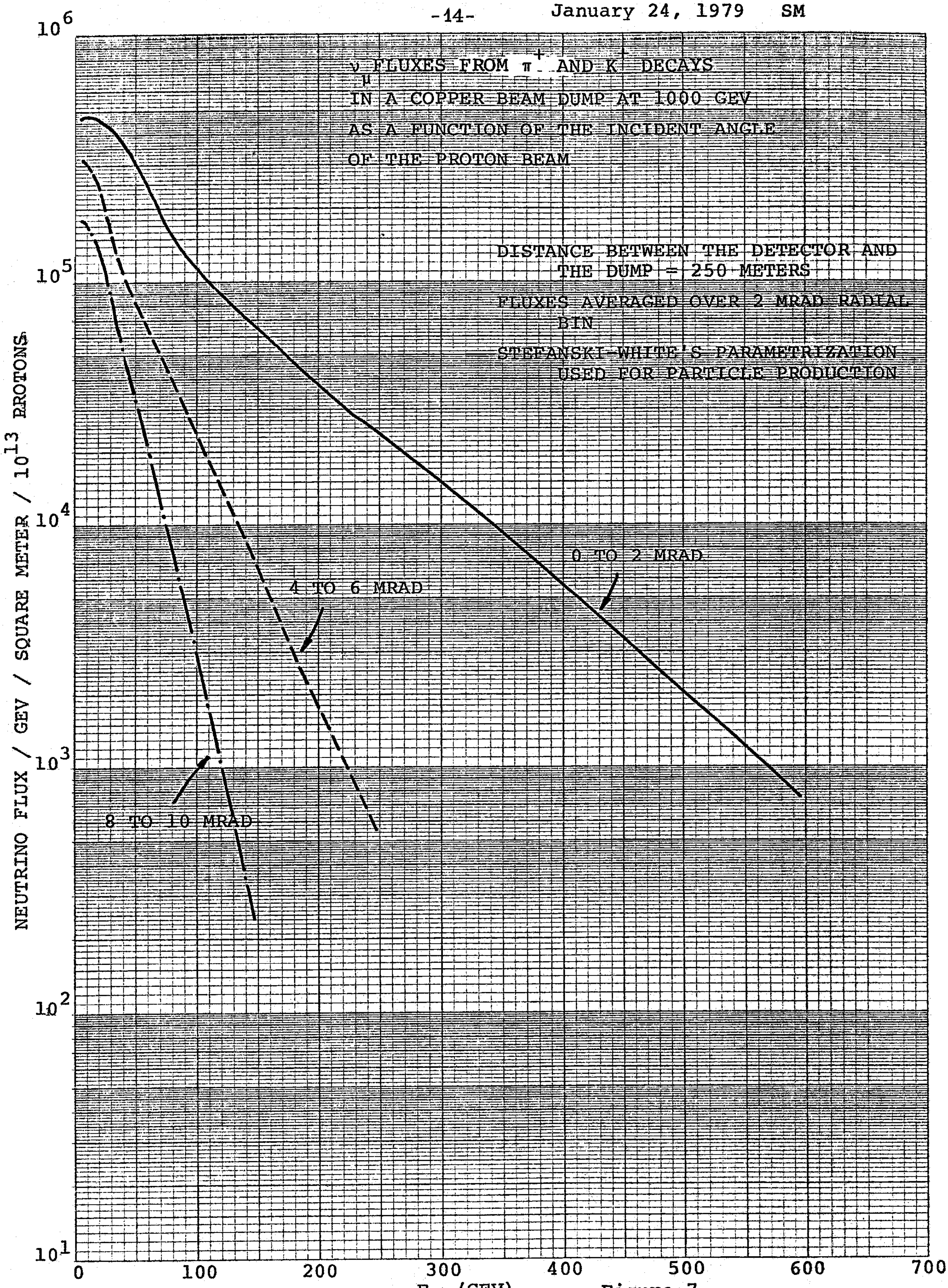

ν_μ AND $\bar{\nu}_\mu$ FLUXES
FROM $\pi^\pm$ AND $K^\pm$ DECAYS
IN A COPPER BEAM DUMP
AT 1000 GEV
DISTANCE BETWEEN THE DETECTOR AND BEAM DUMP = 250 METERS
FLUXES AVERAGED OVER 0 MRAD TO 2 MRAD
STEFANSKI- WHITE'S PARAMETRIZATION USED FOR PARTICLE PRODUCTION
K^+ DECAY
K^- DECAY
π^+ DECAY
π^- DECAY
$\bar{\nu}_\mu$
ν_μ
NEUTRINO OR ANTINEUTRINO FLUX / GEV / SQUARE METER / 10^{13} PROTONS
E (GEV)
10^6
10^5
10^4
10^3
10^2
10^1
0
100
200
300
400
500
600
700

Fig. 6



ν_μ FLUXES FROM π^+ AND K^+ DECAYS
IN A COPPER BEAM DUMP AT 1000 GEV
AS A FUNCTION OF THE INCIDENT ANGLE
OF THE PROTON BEAM
DISTANCE BETWEEN THE DETECTOR AND THE DUMP = 250 METERS
FLUXES AVERAGED OVER 2 MRAD RADIAL BIN
STEFANSKI-WHITE'S PARAMETRIZATION USED FOR PARTICLE PRODUCTION
0 TO 2 MRAD
4 TO 6 MRAD
8 TO 10 MRAD
NEUTRINO FLUX / GEV / SQUARE METER / 10^{13} PROTONS
10^6
10^5
10^4
10^3
10^2
10^1
0
100
200
300
400
500
600
700
E_ν (GEV)

Figure 7.

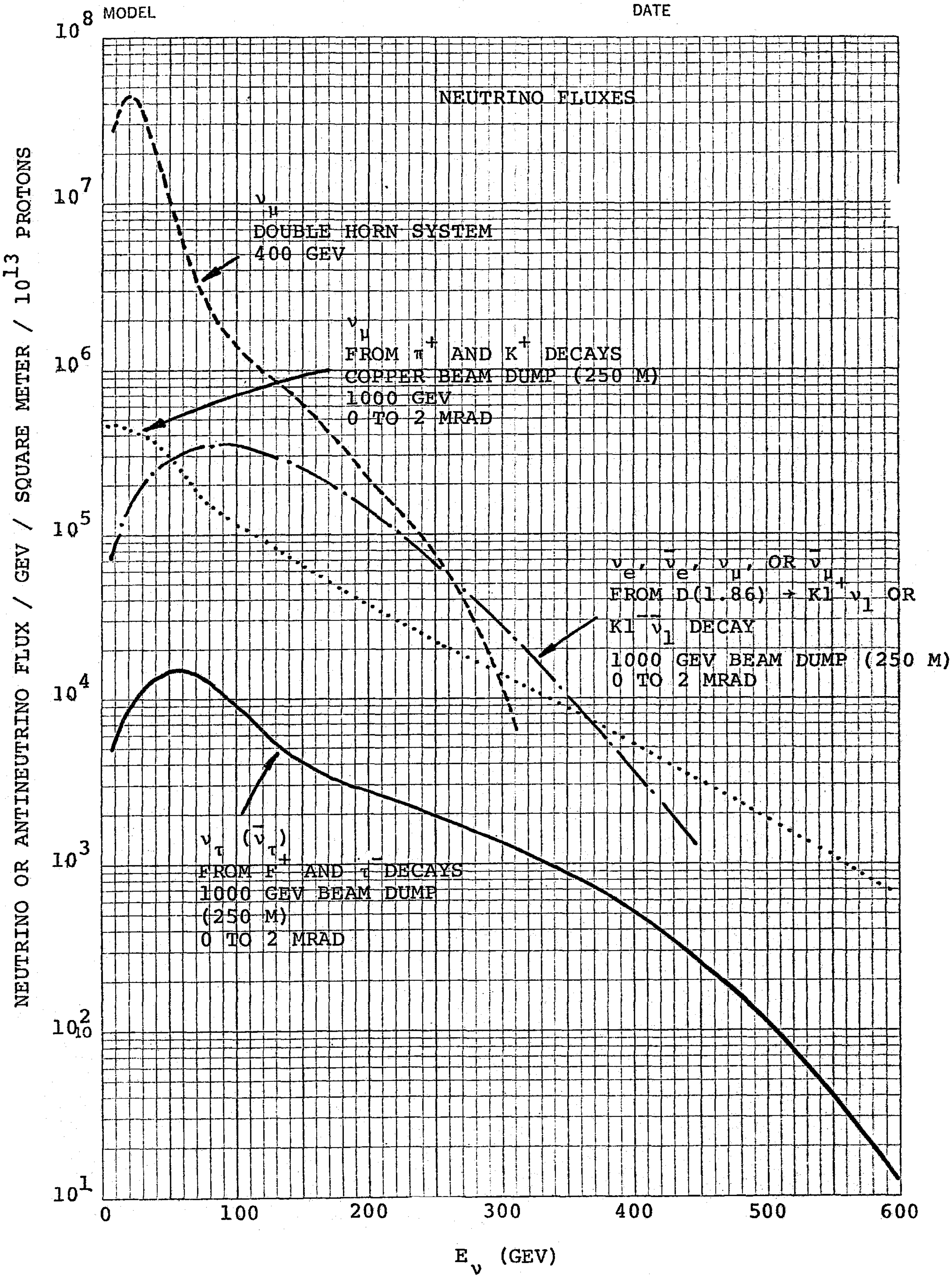

NEUTRINO FLUXES
ν_μ
DOUBLE HORN SYSTEM
400 GEV
ν_μ
FROM π^+ AND K^+ DECAYS
COPPER BEAM DUMP (250 M)
1000 GEV
0 TO 2 MRAD
ν_e, $\bar{\nu}_e$, ν_μ, OR $\bar{\nu}_\mu$
FROM D(1.86) $\rightarrow$ $Kl^+\nu_l$ OR
$Kl^-\bar{\nu}_l$ DECAY
1000 GEV BEAM DUMP (250 M)
0 TO 2 MRAD
ν_τ ($\bar{\nu}_\tau$)
FROM F^+ AND τ^- DECAYS
1000 GEV BEAM DUMP
(250 M)
0 TO 2 MRAD
NEUTRINO OR ANTINEUTRINO FLUX / GEV / SQUARE METER / 10^{13} PROTONS
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
0
100
200
300
400
500
600
E_ν (GEV)

Figure 8.

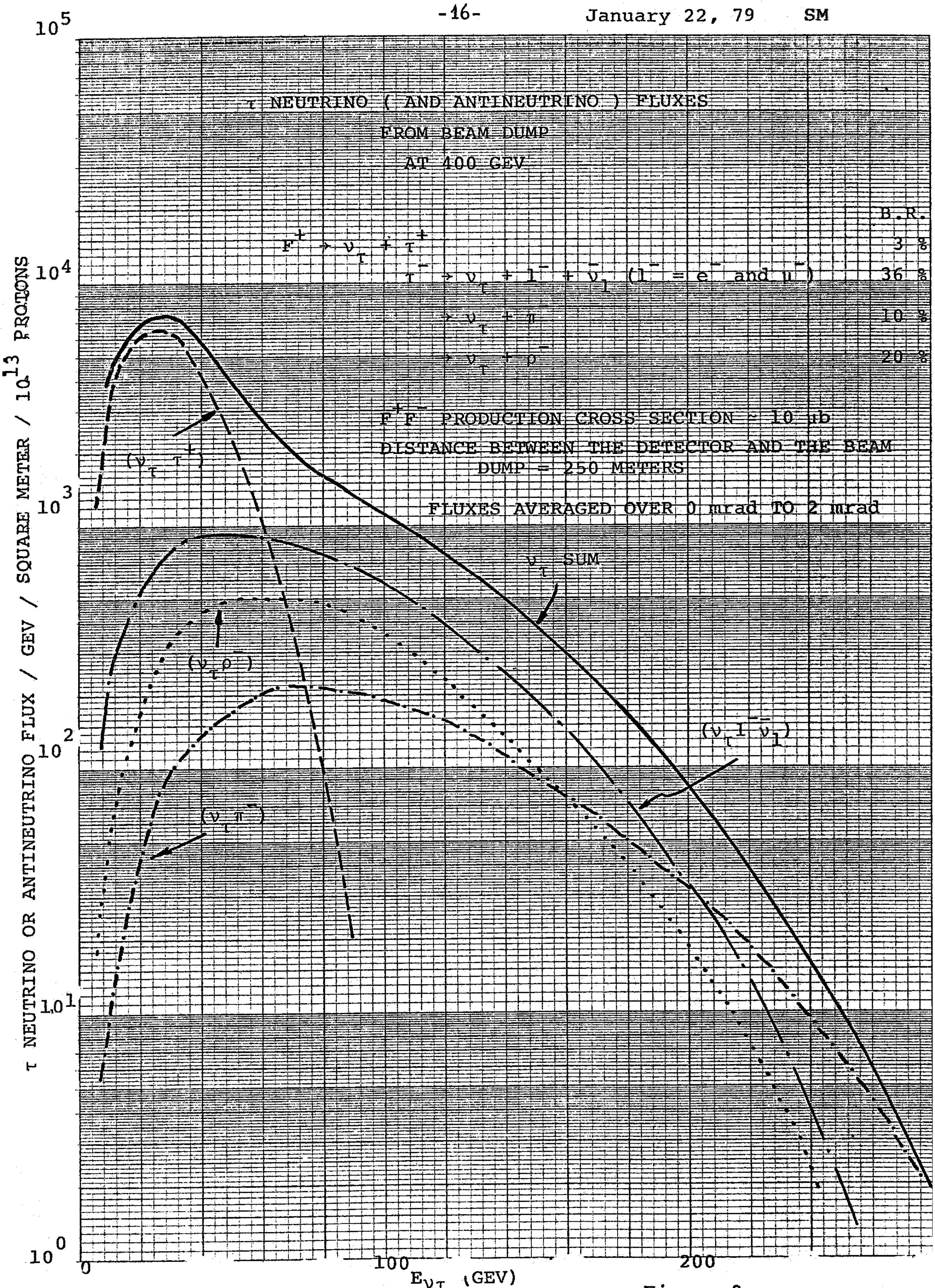

τ NEUTRINO (AND ANTINEUTRINO) FLUXES
FROM BEAM DUMP
AT 400 GEV
B.R.
$F^+ \to \nu_\tau + \tau^+$ 3 %
$\tau^- \to \nu_\tau + l^- + \bar{\nu}_l$ (l^- = e^- and μ^-) 36 %
$\to \nu_\tau + \pi^-$ 10 %
$\to \nu_\tau + \rho^-$ 20 %
F^+F^- PRODUCTION CROSS SECTION ~ 10 μb
DISTANCE BETWEEN THE DETECTOR AND THE BEAM DUMP = 250 METERS
FLUXES AVERAGED OVER 0 mrad TO 2 mrad
ν_τ SUM
$(\nu_\tau \tau^+)$
$(\nu_\tau \rho^-)$
$(\nu_\tau \pi^-)$
$(\nu_\tau l^- \bar{\nu}_l)$
τ NEUTRINO OR ANTINEUTRINO FLUX / GEV / SQUARE METER / 10^{13} PROTONS
10^5
10^4
10^3
10^2
10^1
10^0
0
100
200
E_{ν_τ} (GEV)

Figure 9.

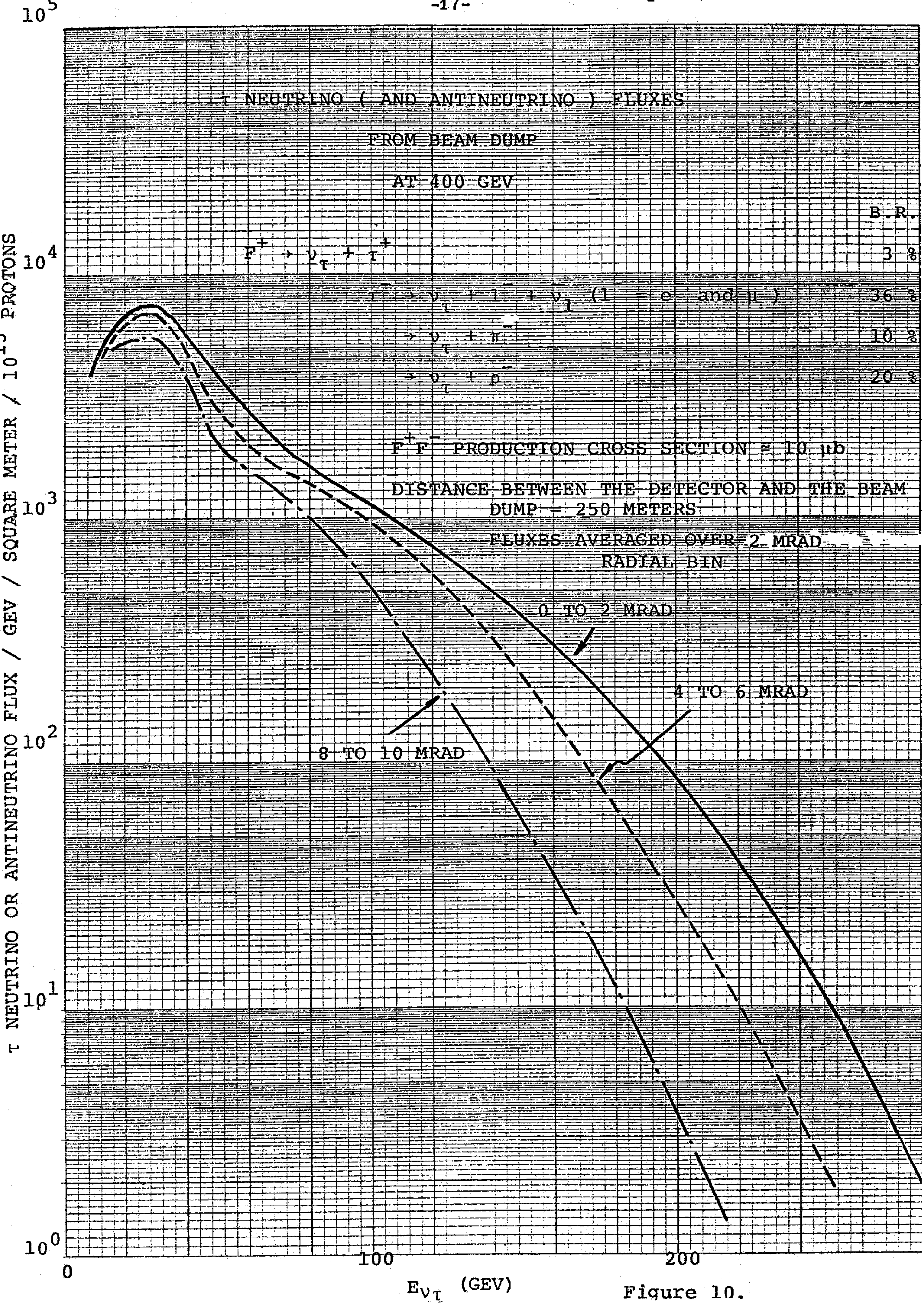

τ NEUTRINO (AND ANTINEUTRINO) FLUXES
FROM BEAM DUMP
AT 400 GEV
B.R.
$F^+ \to \nu_\tau + \tau^+$ 3 %
$\tau^- \to \nu_\tau + l^- + \bar{\nu}_l$ (l^- = e and μ) 36 %
$\to \nu_\tau + \pi^-$ 10 %
$\to \nu_\tau + \rho^-$ 20 %
F^+F^- PRODUCTION CROSS SECTION ≈ 10 μb
DISTANCE BETWEEN THE DETECTOR AND THE BEAM DUMP = 250 METERS
FLUXES AVERAGED OVER 2 MRAD RADIAL BIN
0 TO 2 MRAD
4 TO 6 MRAD
8 TO 10 MRAD
τ NEUTRINO OR ANTINEUTRINO FLUX / GEV / SQUARE METER / 10^{13} PROTONS
10^5
10^4
10^3
10^2
10^1
10^0
0
100
200
E_{ν_τ} (GEV)

Figure 10.